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I

The Problem.—The precise nature of after-images of all sorts and their exact rôle in the determination of sensational and representational states of consciousness subsequent to the appearance of these after-images, remain, in spite of the enormous literature, clouded in doubt and surrounded by controversy. The interminable nature of the primary stimulus, the leakage of light through the sclerotic and iris coats of the eye, the varying sensitivity of the retina bring about the greatest diversity in the visual after-image. These relatively uncontrollable influences combine to make the after-effects of the primary stimulations very uncertain even for a particular observation or series of observations made in a given time, so that the features of after-images are, perhaps, as well characterized by their differences as their likenesses.

From the above it follows that the after-effects of a primary stimulation will affect a secondary stimulation recognizably different at different times. The lack of constancy here, not only in the primary stimulus but in the secondary as well, becomes an important source of error, as will be seen below.

The rôle of the after-image in the general economy of human behavior is wrapped in quite as much uncertainty as the character of the image itself. James[2] expressed the opinion that "we shall probably never know just what part retinal after-images play in determining the train of our thoughts. Judging by my own experiences I should suspect it of being not insignificant." From the large number of cases cited in this reference, it is obvious that the function,

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[1] Graduate student in psychology.

[2] 'Principles,' Vol. II, p. 84.

152.1
a2 60

as well as the nature of the after-effects of stimulation is enveloped in considerable obscurity.

The nature of the after-effects of primary stimulation has long been an object of investigation but relatively little intensive work has been done on the influence of such effects on subsequent stimulation. A quantitative determination of the effects of negative after-images upon the threshold values for secondary color stimulations seems not to have been systematically undertaken. The purpose of the present study[1] is (1) to determine the limens of sensitivity for the commonly denominated primary colors when mixed with black and (2) to determine the limens of sensitivity for each of the same colors after adaptation to (*a*) blue, (*b*) yellow, (*c*) green and (*d*) red. With reference to the influence of adaptation, our problem is, by *how much* does the color and brightness of one stimulus affect the color and brightness of a second stimulus seen directly after it.

With reference to color recognition, Purkinje[2] observed that the primary colors were seen in their true tone as daylight advanced in the following order, blue, green, yellow and red. No limens for sensitivity were determined. Aubert,[3] by varying the daylight illumination on colors 10 mm. square, found the following order of color sensitivity, orange, red, yellow, blue, green. In a later experiment he employed a Masson disc and increased the proportion of color mixed with gray. The order of recognition now changed to orange, yellow, green, red and blue. He found that a little less than two or three degrees of color were needed to determine the recognitive limens of the colors when mixed with black. These experiments do not agree with our results as to the order of sensitivity for the colors red, yellow, blue and green when mixed with black and without the influence of primary stimulation. Our results are confirmed by Raehlemann[4] who, on increasing the intensity of light necessary to give a spectrum, found the recognitive order of sensitivity to be, green, yellow, blue, violet and red. These results are for the limens without the effects of primary stimulation. Geissler[1] determined the limenal saturation values for various colors for each eye separately and for both eyes. The limens for saturation do not follow the order as given by Aubert, Raehlmann and Bentz. For the most part these studies bear upon the recognitive limens for colors independent of the after-effects of primary stimulation.

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[1] An investigation of the recognitive limens for the four primary colors when (1) mixed with gray and (2) mixed with white will follow the present study.

[2] Purkinje, J., *Beiträge zur Kenntniss des Sehens*, 1825, II, p. 109.

[3] Aubert, H., 'Untersuchungen über die Sinnesthätigkeit der Netzhaut,' *Pogg. Annal.*, 1862, CXV., pp. 87–116. Aubert, H., 'Physiologie der Netzhaut,' pp. 138–150.

[4] Raehlmann, E., 'Über Schwellenwerte d. verschiedenen Spectralfarben an versch. Stellen d. Netzhaut. A.F.O.,' 1874, XX., pp. 232–254.

The influence of after-effects of previous stimulation upon color-matches was studied by Buhler,[2] v. Kries,[3] Hering,[4] Tschermak,[5] Watson[6] and others. There seems to be general agreement that the values of color-matches remain undisturbed by after-effects of previous stimulation, especially (v. Kries) so far as these matches apply to foveal vision.

After-effects of various kinds of primary stimuli have received the attention of a large number of investigators. As early as 1743 Buffon[7] reported that the after-image of a color fused with the background of another color (secondary stimulation) in such a way as to form a third color. It is interesting that the determination of the recognitive limens of colorless and chromatic secondary stimuli as affected by after-images of primary stimuli received little attention. Investigators, for the most part, observed qualitative changes in sensations of secondary stimulation due to previous stimulation.[8]

II

The apparatus employed in this study consisted of a four-spindle color-mixer, an induction chamber, a modified Kühlmann time apparatus and a seconds pendulum.

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[1] Geissler, L. R., 'Exp. on Color Saturation,' *Am. Jour. Psych.*, Vol. 24, pp. 171–179.

[2] Buhler, Dissert., University Freiburg, 1913.

[3] v. Kries, *Arch. f. Añat.*, 1878.

[4] Hering, *Arch. f. d. ges. Physiol.*, LIV., 1893.

[5] Tschermak, *Arch. f. d. ges. Physiol.*, 1898.

[6] Watson, *Proc. Roy. Soc. London*, 1913.

[7] Buffon, 'Dissert. sur les Couleurs Accidentelles,' Memoires de l'Acad. de Sciences de Paris, 1743, p. 213.

[8] Parsons, 'An Introduction to the Study of Color Vision,' pp. 105–112.

Four-Spindle Color-Mixer.[1]—The color-mixer, shown in Plates I., II., III., was equipped with an adjustable shutter *A*, with a micrometer screw attachment eight threads to the inch read on scale *B* in eighths of inches, and a hand drive *C* scaled to one hundred divisions for a full turn on *D*. Clutch *F* when set (*F′* in the phantom picture, Plate II.) secured the contact of wheel *E* (*E′* in Plate II.) with both wheel *G* attached to the motor *K*, and wheel *H* on the spider *O*. Wheel *M* on the same axis as wheel *H* was thus revolved when the clutch was set and the motor started. Special red, yellow, green, and blue color discs were held securely on the four wheels *M* of the spider by the thumb nuts *N*. (A full description of these discs is given below.) The photograph of the back of the apparatus (Plate III.) shows the method by which the revolving spider was made secure in each of the four positions by pin *P* extending through groove *R*. This enabled each of the discs to be brought into position for observation. A small shield *S* fitted over the adjustable shutter *A* in such a manner that on closure of the shutter the circular opening, as shown in the phantom picture, coincided with the circular opening in the shield. A large neutral gray shield *T*, which in the photograph appears below the apparatus, covered the entire front of the mixer, the small shield *S* being behind opening *V*.

Induction Chamber.—The dull black induction chamber was provided with interior lights. Two of these (16 c.p. each) indirectly illuminated sheets of paper eighteen inches square of the Milton Bradley standard red, blue, yellow and green. The end of the hood to the induction chamber was so shaped as to fit the face, thus excluding all other light stimuli.

Modified Kühlmann Time Apparatus.—Reference to the time apparatus, Plate IV., will make clear its mode of operation. As soon as the electromagnets became active, they attracted the armature 6, attached to the clutch 1. This

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[1] This piece of apparatus was designed by Dr. A. P. Weiss, who kindly supervised the making of Plates I., II. and III. and who rendered other valuable technical assistance. A more complete account of this piece of apparatus will be published in the near future.

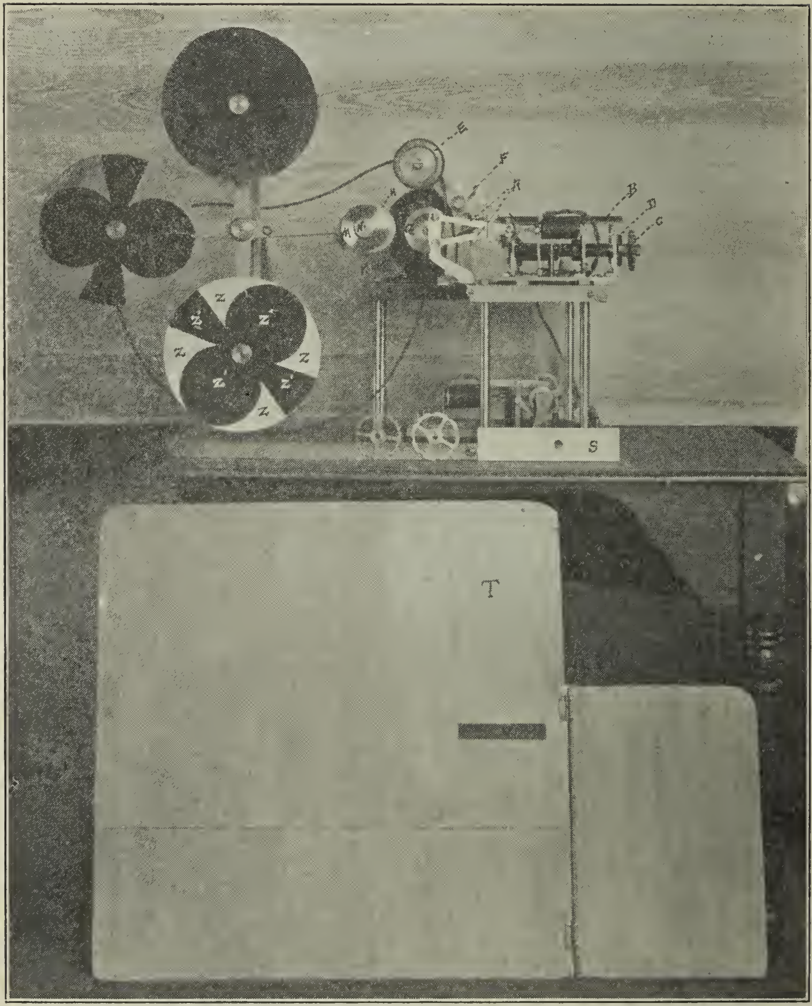

Plate I. Front View of Complex Color-mixer.

(Almack and Arps.) PLATE 2.

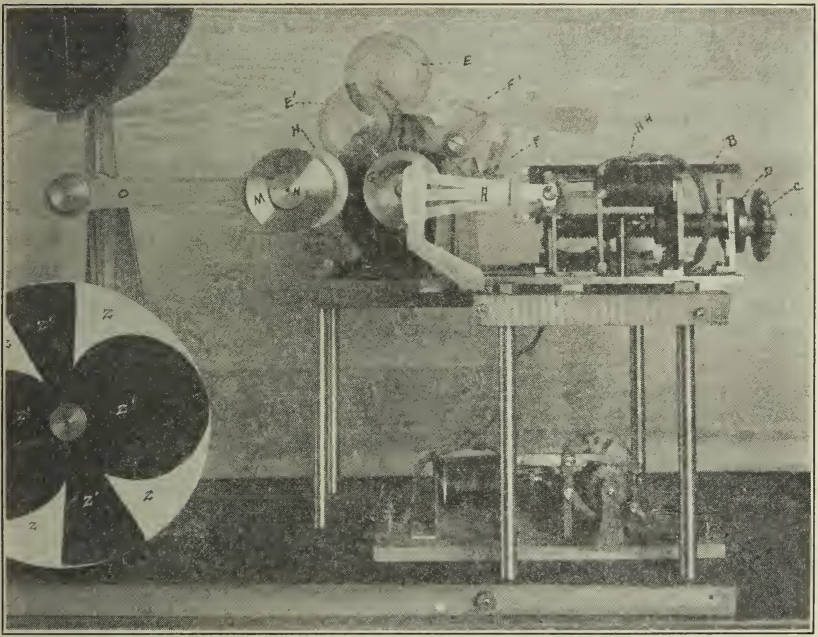

Plate II. Front View of Complex Color-mixer. Phantom Picture.

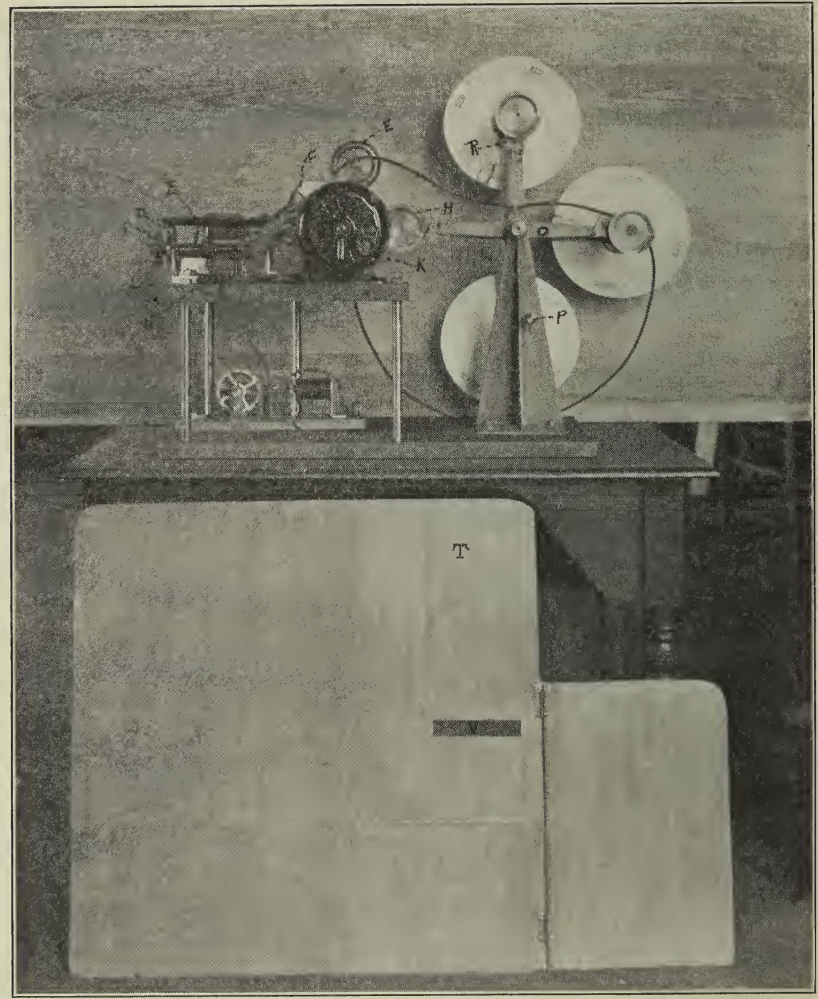

Plate III. Back View of Complex Color-mixer.

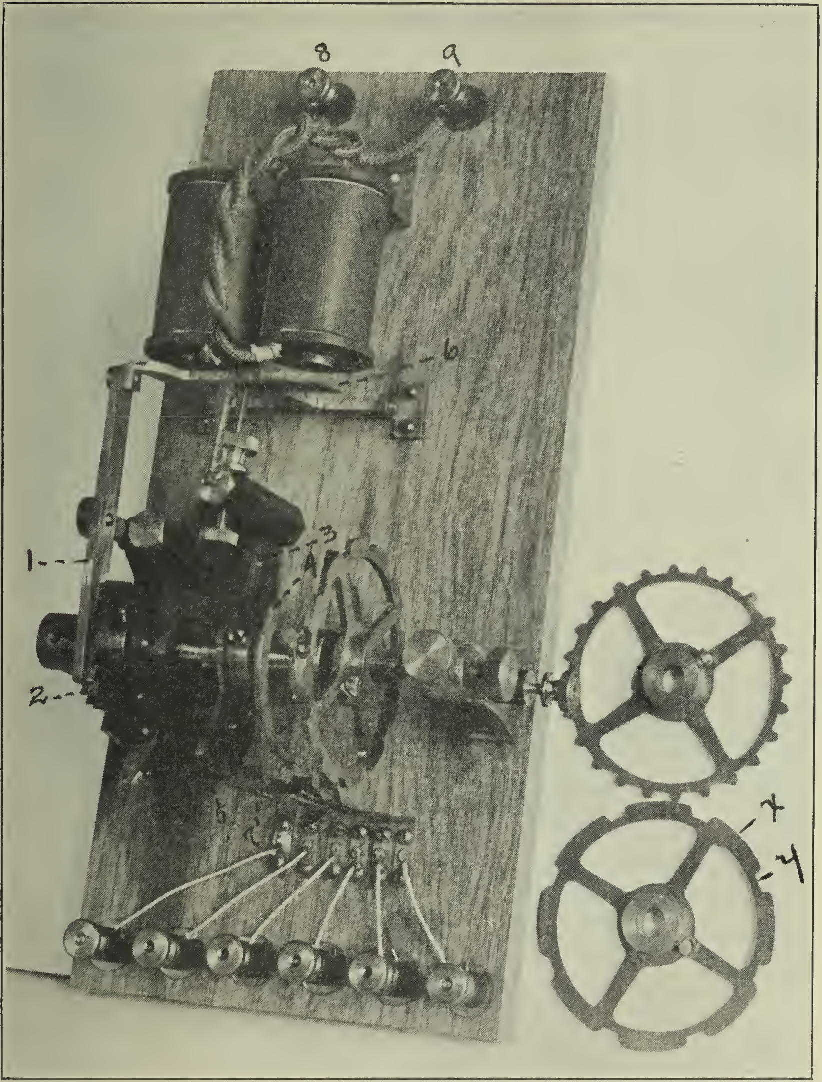

PLATE IV. Modified Kühlmann Time Apparatus.

clutch fitted into the toothed wheel 2 and each attraction of the magnet pulled the wheel one notch forward. The two wheels, 3 and 4, on the same axis with wheel 2, were so cut that at certain intervals they formed contacts with connections 5 and 7 respectively, while at other intervals, there was no contact. *X* and *Y*, referring to the separate wheels at the right of the apparatus, designate contact and no contact respectively.

Seconds Pendulum.—The seconds pendulum is a modified form of similar pieces of apparatus common to psychological laboratories. In this particular pendulum the contact was made by the point of the pendulum swinging through a mercury cup.

Color Discs.—Special color discs were made by pasting overlapping black paper discs five and one eighth inches in diameter on Milton Bradley color discs ten inches in diameter of the standard colors blue, yellow, green and red. Two strips of the same black paper, of ten degrees each, were added to the color portion. The character of the discs is shown in the photographs (Plates I. and II.). The color portions are designated by Z, the added black strips by Z′.

Light Restriction Hood.—A specially devised hood of gray pasteboard and about eight inches in length was so shaped as to fit the face. This hood was used in observing the secondary stimuli, limiting the light that might affect the eyes to that coming from the shutter opening and adjacent area on the gray shield.

III

The manner of articulating the various pieces of apparatus is set forth in Plate V. When the circuit was closed through key, *K*, each contact of the pendulum *S* with the mercury cup 1, completed the circuit through posts 8 and 9 of the time apparatus *T*, thus causing the wheels 3 and 4 (Plate IV.), to revolve one notch at a time. Contact between wheel 3, and connection 5 completed the circuit through the color-mixer. The shutter *A* was then opened by actuation of the armature, to which it was attached, by the electro-magnets (*AA*, Plate II.). The circuit was made through the induc-

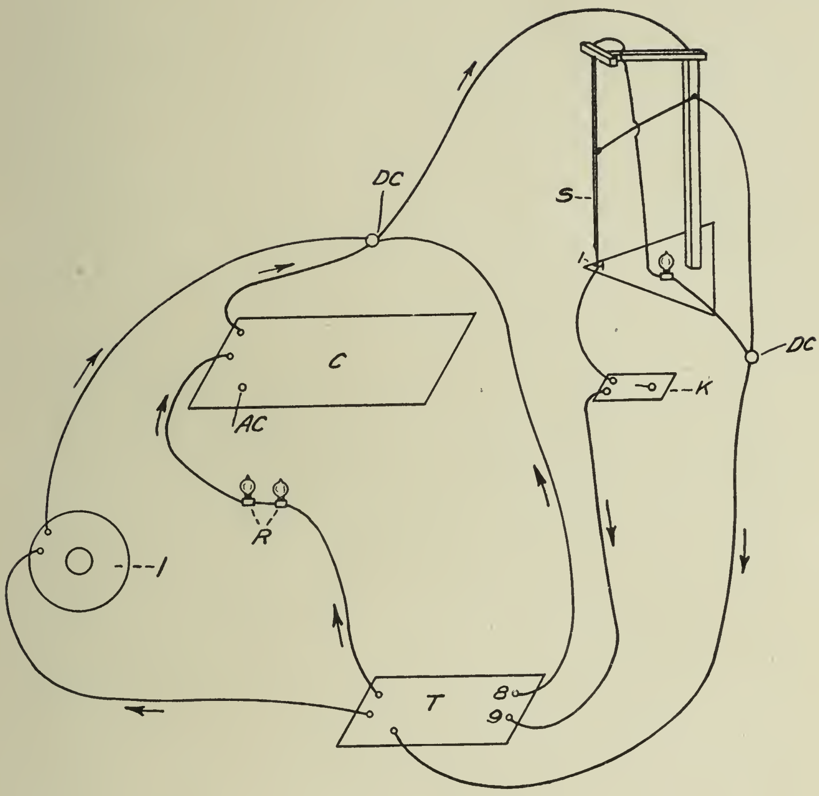

Plate V. Diagrammatic Arrangement of Apparatus. *I*, Induction Chamber; *C*, Complex Color-mixer; *S*, Seconds-pendulum; *T*, Kühlmann Time Apparatus; *K*, Key; *DC*, Direct Current; *AC*, Alternating Current; *R*, Resistance.

tion chamber when wheel 4 came in contact with connection 7. This wheel (4) controlled the duration of the illumination of the inducing colors (primary stimuli). The motor was attached to an alternating current and controlled by a switch (*W*, Plate IV.).

IV

Observers.—Thirty-five observers functioned in the experiment, all of whom were familiar with the important facts of color vision. Twenty-seven were members of elementary classes in psychology, five members of a class in experimental psychology and three were instructors in the department. Discrepancies in color judgment were avoided, so far as possible, by testing each observer's color vision by means of the Holmgren wools. Observers who could not pass the test satisfactorily were rejected.

Procedure.—The observer was seated facing the mixer directly in front and about one and a half feet from the shutter opening. The induction chamber, at the side of the observer, was so arranged that the position for induction could be attained by merely turning the head to the right. The distance from the shutter opening was kept constant throughout.

Before the experiment was started, instructions were given as to the duration of the primary stimulus (induction), the interval between induction and the opening of the shutter and the manner of reporting the color.

Method Without Induction.—The first judgment was made with the micrometer screw set at five eighths, the second at six eighths and so on, the registering point of the screw being moved one eighth of an inch after each judgment by means of the hand drive *C*. The portion of the revolving disc exposed at five eighths approximated black, but as the micrometer screw on which the small shield and shutter were attached was moved to the succeeding eighths, the degree of color increased with each exposure. The shutter exposure moved from a point near the center of the disc, where there was minimal saturation, toward greater saturation at the outer edge of the disc. Exposures of the same disc, with increasing degrees of saturation, were continued until the color was recognized and confirmed by two immediately following judgments. If the judgment blue, for example, were made the two following judgments must be given as blue or the color was not considered as finally recognized. The limen of sensitivity without induction was first determined.

Method With Induction.—The instructions were repeated with reference to the duration of induction (primary stimulation), the interval between induction and the shutter opening, and the interval between closure of the shutter and the reappearance of the primary stimulus. The position for receiving the primary stimulus was assumed by the observer and the entire apparatus started as in previous experiments. The observer's attention was directed for a period of five seconds to the inducing color in the center of which was placed a small cross, as a fixation point. Two seconds intervened between the cessation of the primary stimulus and the appearance of the secondary stimulus through the shutter opening. This afforded ample opportunity for the observer to fixate the opening through the improvised light restriction hood. The revolving disc was exposed through the shutter opening for a period of one second. An interval of four seconds followed in which the observer reported the color as cognized and prepared for the second induction. The influence of one inducing color was determined in successive experiments for each of the four colors before employing a different inducing color. Experiments were stopped when evidence of fatigue appeared.

The order of presentation of the discs was changed to avoid as far as possible the factor of anticipation. Moreover, none of the observers were aware of the number of colors employed, for the reason that the substitution of the discs and the regulation of the degree of color exposed, were controlled from behind the shield (*T*, Plate I.).

V

Data.—Table I. gives one observer's judgments from the initial to the final micrometer readings for all the secondary

Table I

Judgments of Observer I

Inducing Colors (Primary Stimuli)	Color Disks (Secondary Stimuli)	Micrometer Readings in Eighths												
		5	6	7	8	9	10	11	12	13	14	15	16	17
None...	Blue....	Bk	Bk	Bk	Bl									
	Yellow..	Bk	Bk	Bk	Bk	Bk	Br	Br	DkG	DkOl	Ol	LtOl	LtOl	YG
	Green...	Bk	Bk	Bk	Bk	DkG	G							
	Red....	Bk	Bk	Bk	Bk	Bk	P	Br	Br	DkR	R			
Blue....	Blue....	Bk	Bk	Bk	Bk	Bl								
	Yellow..	Bk	Bk	Bk	OlG	OlG	OlG	OlG	OlG	LtOl	LtOl	YG	Y	
	Green...	Bk	Bk	Bk	Bk	DkG	G							
	Red....	Bk	Bk	Bk	Bk	Br	P	Br	Br	Br	DkR	R		
Yellow..	Blue....	Bk	Bk	Bk	Bl									
	Yellow..	Bk	Bk	DOl	DOl	Ol	Ol	Ol	Ol	Ol	YOl			
	Green...	Bk	DkG	G										
	Red....	Bk	Bk	Bk	Bk	Br	Br	Br	DkR	R				
Green...	Blue....	Bk	Bk	Bl										
	Yellow	Bk	Bk	Br	Bk	Bk	DkG	OlG	OlG	Ol	LtOl	YOl	Y	
	Green...	Bk	DkG	G										
	Red....	Bk	Bk	Bk	Br	P	RP	RBr	RBr	R				
Red....	Blue....	Bk	Bk	Bl										
	Yellow..	Bk	Bk	Bk	OlG	OlG	OlG	OlG	OlG	LtOl	LtOl	YG	Y	
	Green...	Bk	DkG	G										
	Red....	Bk	Bk	Bk	Bk	Br	Br	Br	Br	Br	Br	Br	Br	BrR

LtOl = light olive. The equivalents of the micrometer readings in degrees of color are found under Table XXIII.

stimuli with and without the influence of primary stimulation. A similar table was made for each of the remaining thirty-four observers but not incorporated separately in this study. The data in these thirty-five tables were rearranged as shown in Table II., except that Table II. contains only the judgments made on 'blue.' Tables III. to VII. inclusive summarize the data under Table II. The judgments on red, green and yellow are given in condensed form under Tables VIII. to XXII. inclusive.

The initial micrometer readings are the same for all colors except green which is three eighths. The final readings are seventeen, twenty, nineteen and eleven eighths for blue, yellow, red and green respectively. The degrees of color equivalent to these micrometer readings are found under Table XXIII.

In the condensed data of nearly all the tables there are

TABLE II

SUMMARY OF JUDGMENTS OF ALL OBSERVERS FOR THE BLUE DISK

Obs.		Micrometer Readings 5/8, Primary Stimuli					Micrometer Readings 6/8, Primary Stimuli					Micrometer Readings 7/8, Primary Stimuli				
		Bl	Y	Gr	R	N	Bl	Y	Gr	R	N	Bl	Y	Gr	R	N
1	Judgments	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bl	Bl	Bk
2	"	DkBl	Bk	DkBl	Bk	Bk	Bk	DkBl	Bl	DkBl	Bk	Bl	Bl	Bl	Bl	Bk
3	"	Bk	Bk	Bk	Bk	Br	PBl	DkBr	P	DkBr	P	DkP	P	P	Bl	Bl
4	"	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bl	Bk	Bk	Bk	DkV	Bl	Bk
5	"	Bk	Bk	Bk	Bk	Bk	BlBk	BlBk	Bk	Bk	Bk	BrBk	Bl	Bk	Bk	Bk
6	"	Bk	DkGr	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	DkBl	Bk	Bk	Bk
7	"	Bk	Gray	P	Bk	P	Bk	Gray	P	P	Bl	PBk	Bl	PBl	P	BlP
8	"	Bk	BrBk	BlBk	Bk	Bk	Gr	BlBk	BlBk	Bk	Bk	Bl	BlBk	BlBk	R	Bk
9	"	Bl	Bl	Bl	Bk	Bk	Bl	Bl	Bl	DkBl	Bk	Bl	Bl	Bl	Bl	BlBk
10	"	Bk	Bk	PBk	Bk	Bk	Bk	BlBk	BlBk	Bk	Bk	BlBk	BlBk	DkBl	PBk	Bk
11	"	P	Bk	DkP	Bk	Bk	P	DkP	DkP	Bk	Bk	Bl	P	DkP	DkP	Bk
12	"	BlBk	Bk	BkBl	Bk	Bk	BlBk	BlBk	DkBl	Bk	Bk	BlBk	Bl	Bl	BlBk	Bk
13	"	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk
14	"	Bk	Bk	Bk	BlBk	Bk	DkBl	DkBl	BlBk	Bl	Bk	Bl	Bl	Bl	Bl	R
15	"	Bk	PBk	Bk	Bk	Bk	BlBk	Bk	Bk	Bk	Bk	Bl	BlBk	BlBk	BlBk	Bl
16	"	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bl	Bl	Bk
17	"	DkGr	GrBk	Bk	Bk	DkGr	Bk	GrBk	BlBk	BrBl	DkGr	Bk	Bl	Bl	Bl	DkGr
18	"	Bk	DkBl	Bk	Bk	Bk	Bk	Bl	DkBl	DkGr	Bk	Bk	Bl	Bl	DkBl	Bk
19	"	Bk	PBr	RBr	Bk	Bk	Bk	PBr	RBr	Bk	Bk	RBk	PBr	RBr	PBk	Bk
20	"	BlBk	Bk	Bk	Bk	Bk	Bl	Bk	BlBk	Bl	Bk	Bl	BlBk	Bl	Bl	Bk
21	"	BlBk	Bk	Bl	PBk	Bk	Bl	Bk	Bl	BlBk	BlBk	Bl	Bk	Bl	Bl	Bl
22	"	BlBk	PBk	Bl	BlBk	Bk	Bl	BlBk	Bl	Bl	BlBk	Bl	Bl	Bl	Bl	Bl
23	"	Bk	BlBk	BlBk	Bk	R	Bk	Bl	Bl	Gr	R	BlBk	Bl	Bl	GrBk	Bk
24	"	DkBl	Bl	Bl	Bl	Bk	DkBl	Bl	Bl	Bl	Bk	Bl	Bl	Bl	Bl	DkBl
25	"	DkBr	Bk	DkBr	DkR	Bk	Bk	DkP	DkP	DkBl	Br	DkP	BlP	DkBl	Bl	PBr
26	"	Bk	Bk	BlBk	BlBk	Bk	BlBk	Bk	P	Bk	Bk	Bl	Bk	Bl	Bl	Bk
27	"	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Gr	Bk
28	"	DkBl	BlBk	DkP	Bk	DkP	Bl	Bl	DkP	LBk	DkP	Bl	Bl	PR	BlBk	LtP
29	"	Bk	Bk	Bk	Bk	Bk	Bk	Bk	BlBk	BlBk	Bk	Bk	Bk	DkBl	DkBl	Bk
30	"	Bk	Bk	Bk	Bk	BlBk	Bk	Bk	Bk	Bk	BlBk	BlBk	Bk	Bk	BkBl	BkBk
31	"	PBk	Bk	Bk	Bk	GrBk	DkBl	BrBk	Bk	GrBk	GrBk	Bl	Bk	Bk	Bk	GrBk
32	"	BlBk	BlBk	Bk	Bk	Bk	BlBk	BlBk	Bk	BlBk	Bk	BlBk	BlBk	BlBk	BlBk	PBk
33	"	GrBk	PBk	Bk	Bk	BlBk	PBk	PBk	Bk	P	BlBk	GrBk	Bl	RBk	Bk	BlBk
34	"	Bk	Bk	Bk	BlBk	Bk	BlBk	Bl	DkBl	DkBl	DkBl	DkBl	Bl	Bl	Bl	Bl
35	"	Bl	Bk	V	Bl	Bk	Bl	Bk	V	Bl	Bk	Bl	Bl	V	Bl	BlBk

Abbreviations.—DkBl = Dark Blue; RBr = Red Brown; V = Violet; P = Purple.

SUMMARY OF JUDGMENTS OF ALL OBSERVERS FOR THE BLUE DISK

Obs.		Micrometer Readings 8/8, Primary Stimuli					Micrometer Readings 9/8, Primary Stimuli					Micrometer Readings 10/8, Primary Stimuli				
		Bl	Y	Gr	R	N	Bl	Y	Gr	R	N	Bl	Y	Gr	R	N
1	Judgments	Bk	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
2	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bk	Bl	Bl	Bl	Bl	DkBl
3	"	DkP	PBr	DkP	Bl	Bl	PBl	P	PBl	Bl	Bl	RP	DkBl	BlP	Bl	Bl
4	"	Bk	BlBk	V	Bl	Bk	Bk	PBk	DkBl	Bl	Bk	Bk	Bl	Bl	Bl	DkBl
5	"	BkBl	P	Bk	Bk	BlBk	BlBk	Bl	Bk	Bl	Bl	Bl	Bl	Bk	Bl	Bl
6	"	Bl	Bl	Bl	Bl	Bk	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
7	"	PBk	Bl	BlP	P	BlP	P	Bl	BlP	Bl	BlP	P	Bl	Bl	Bl	BlP
8	"	Br	BlBk	Bl	DkBr	Bl	Bk	BlBk	Bl	Bl	Bl	DkBl	Bl	Bl	Bl	Bl
9	"	Bl	Bl	Bl	Bk	BlBk	Bl	Bl	Bl	Bl	BlBk	Bl	Bl	Bl	Bl	Bl
10	"	BlBk	DkBl	Bl	BlBk	Bk	BlBk	DkBl	Bl	BlBk	BlBk	DkBl	Bl	Bl	DkBl	BlBk
11	"	Bl	LtP	Bl	P	P	Bl	Bl	Bl	Bl	PBl	Bl	Bl	Bl	Bl	Bl
12	"	Bl	Bl	Bl	BlBk	BlBk	Bl	Bl	Bl	Bl	BlBk	Bl	Bl	Bl	Bl	Bl
13	"	Bk	Bk	Bk	Bk	Bk	Bl	Bk	Bl	Bk	Bk	Bl	Bk	Bl	Bl	Bl
14	"	Bl	Bl	Bl	Bl	Bk	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
15	"	Bl	PBk	Bl	Bl	Bl	Bl	BlBk	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
16	"	Bk	Bl	Bk	Bl	Bk	BlBk	Bl	Bl	Bl	Bk	Bl	Bl	Bl	Bl	Bl
17	"	Bk	Bl	Bl	Bl	DkGr	Bl	Bl	Bl	Bl	DkGr	Bl	Bl	Bl	Bl	Bl
18	"	Bk	Bl	Bl	Bl	BlBk	Bl	Bl	Bl	Bl	DkBl	Bl	Bl	Bl	Bl	Bl
19	"	RBr	PBl	P	Bl	P	Bl	PBr	P	Bl	P	Bl	Bl	Bl	Bl	BlP
20	"	Bl	Bl	Bl	Bl	Bk	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
21	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
22	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
23	"	Bl	Bl	Bl	GrBk	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
24	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
25	"	BlP	DkBl	Bl	Bl	P	DkBl	Bl	Bl	Bl	P	Bl	Bl	Bl	Bl	Bl
26	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
27	"	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bl	Bl	Bk	Bl	Bl	Bl	Bl	Bk
28	"	Bl	Bl	BlBk	DkBl	BlP	Bl	Bl	DkBl	Bl	BlP	Bl	Bl	Bl	Bl	P
29	"	BlBk	Bl	Bl	Bl	Bk	Bl	Bl	Bl	Bl	BlBk	Bl	Bl	Bl	Bl	DkBl
30	"	BlBk	Bk	BlBk	BlBk	BlBk	DkBl	BlBk	BlBk	BlBk	BlBk	Bl	BlBk	DkBl	Bl	BlBk
31	"	Bl	PBr	GrBk	Bk	GrBk	Bl	DkBl	Bk	Bl	Bl	Bl	PBl	BlBk	Bk	Bk
32	"	Bl	BlBk	BlBk	nBl	BlBk	Bl	PBl	BlBk	Bk	Gr	Bl	Bl	Bl	Bl	Bl
33	"	Bl	Bl	PBk	DkP	Bl	Bl	Bl	P	DkP	Bl	Bl	Bl	Bl	PBl	Bl
34	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
35	"	Bl	Bl	Bl	Bl	DkBl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl

Abbreviations.—DkBl = Dark Blue; RBr = Red Brown; V = Violet; P = Purple.

SUMMARY OF JUDGMENTS OF ALL OBSERVERS FOR THE BLUE DISK

Obs.		Micrometer Readings 11/8, Primary Stimuli					Micrometer Readings 12/8, Primary Stimuli					Micrometer Readings 13/8, Primary Stimuli				
		Bl	Y	Gr	R	N	Bl	Y	Gr	R	N	Bl	Y	Gr	R	N
1	Judgments	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
2	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
3	"	DkBl	Bl	DkP	Bl	Bl	BlP	Bl	DkBl	Bl	Bl	Bl	Bl	PBl	Bl	Bl
4	"	DkV	DkBl	Bl	Bl	Bl	DkBl	VBk	Bl	Bl	Bl	Bl	DkBl	Bl	Bl	Bl
5	"	Bl	Bl	BlBk	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
6	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
7	"	BlP	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
8	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
9	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
10	"	Bl	Bl	Bl	Bl	DkBl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
11	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
12	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bk	Bl	Bl	Bl
13	"	Bl	Bk	Bl	Bl	Bl	Bl	Bk	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
14	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
15	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
16	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
17	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
18	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
19	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
20	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
21	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
22	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
23	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
24	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
25	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
26	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
27	"	Bl	Bl	Bl	Bl	Bk	Bl	Bl	Bl	Bl	Bk	Bl	Bl	Bl	Bl	Bk
28	"	Bl	Bl	Bl	Bl	DkBl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
29	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
30	"	Bl	BlBk	P	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
31	"	Bl	PBl	DkBl	BlBk	Bk	Bl	Bl	Bl	BlBk	BlBk	Bl	Bl	Bl	Bl	BlBk
32	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
33	"	Bl	Bl	Bl	PBl	Bl	Bl	Bl	Bl	PBl	Bl	Bl	Bl	Bl	PBl	Bl
34	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
35	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl

Abbreviations.—DkBl = Dark Blue; RBr = Red Brown; V = Violet; P = Purple.

SUMMARY OF JUDGMENTS OF ALL OBSERVERS FOR THE BLUE DISK

Obs.		Micrometer Readings 14/8, Primary Stimuli					Micrometer Readings 15/8, Primary Stimuli					Micrometer Readings 16/8, Primary Stimuli				
		Bl	Y	Gr	R	N	Bl	Y	Gr	R	N	Bl	Y	Gr	R	N
1	Judgments	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
2	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
3	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
4	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
5	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
6	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
7	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
8	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
9	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
10	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
11	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
12	"	Bl	Bk	Bl	Bl	Bl	Bl	Bk	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
13	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
14	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
15	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
16	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
17	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
18	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
19	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
20	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
21	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
22	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
23	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
24	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
25	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
26	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
27	"	Bl	Bl	Bl	Bl	Bk	Bl	Bl	Bl	Bl	Bk	Bl	Bl	Bl	Bl	Bl
28	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
29	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
30	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
31	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
32	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
33	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
34	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
35	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl

Abbreviations.—DkBl = Dark Blue; RBr = Red Brown; V = Violet; P = Purple.

certain judgments which involve two colors, or a color and a brightness, as the judgments YGr (yellow green), BlGr (blue green), DkBl (dark blue) and GrBk (greenish black). The variety of judgments was condensed according to the following directions:

1. When brightness was coupled to a color in a judgment the designated brightness was omitted from the record. Dark blue, for example, was recorded as blue.

2. When a judgment involved two colors of equal prominence that color was recorded which corresponded to the color on the disc. Purple blue was recorded as blue.

3. When a judgment involved two colors neither the one nor the other of which was the color on the disc that color was recorded which nearest resembled the disc. The judgment purple brown was recorded purple when the color on the disc was blue.

4. When a single color judgment, or a color judgment coupled with a brightness failed to correspond to the color on the disc the color judgment alone was recorded. The judgment dark brown on the green color disc was recorded as brown.

The 'Aggregation of Re-classified Judgments,' found in Tables III. to XXII. inclusive, constitutes a condensed grouping of all the data. Tables IV. to XXII. inclusive are abridgments of data analogous to that contained in the upper half of Table III.

Table XXIII. contains the degrees of color which were mixed with black for each micrometer reading. For green and red the amount of color was slightly less than for the blue and yellow for the 4/8 and 5/8 readings. In a comparison of the recognitive thresholds this gives a slight advantage or disadvantage to the former colors depending upon the nature of the primary stimulation.

The Curves.—Separate curves (ascending) for each color of the four discs under the five conditions of influence together with the curves (descending) for the accompanying 'black' judgments were plotted from the 'Aggregate Judgments' given in the tables. Ten curves were, therefore, drawn for each color. To prevent crowding the curves two figures are devoted to each color, as Fig. 1 and Fig. 2 for the blue disk. The numerals along the ordinate axes indicate the distribution of the observers with reference to judgments of color for the different micrometer readings which are found along the abscissæ. Beneath these readings are the corresponding degrees of color.

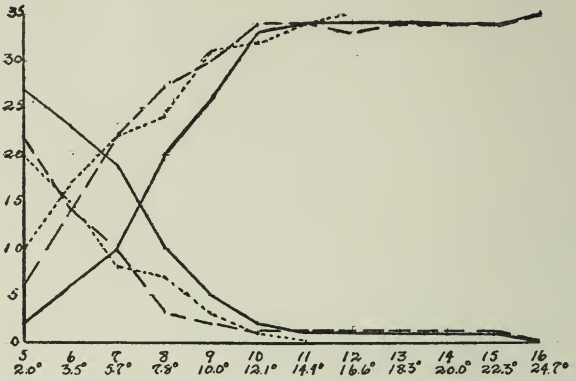

Fig. 1. Recognitive Limens for the Blue Disk.

The intersections of the 'color' curves with the 'black'

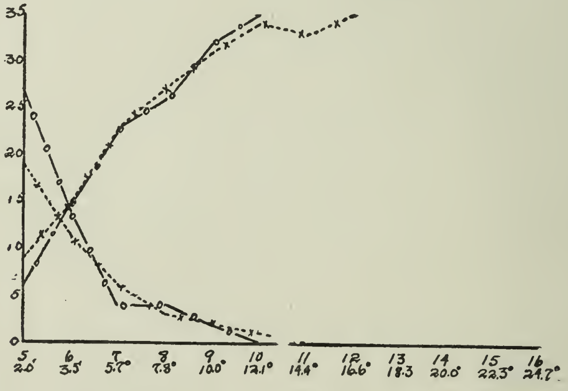

Fig. 2. Recognitive Limens for the Blue Disk. Points of intersection of curves = recognitive limens. Ascending curves = color judgments; descending curves = black judgments. —— = no influence; . . . . . . = blue influence; —— —— = yellow influence; . . . * . . . = green influence; ——o—— = red influence.

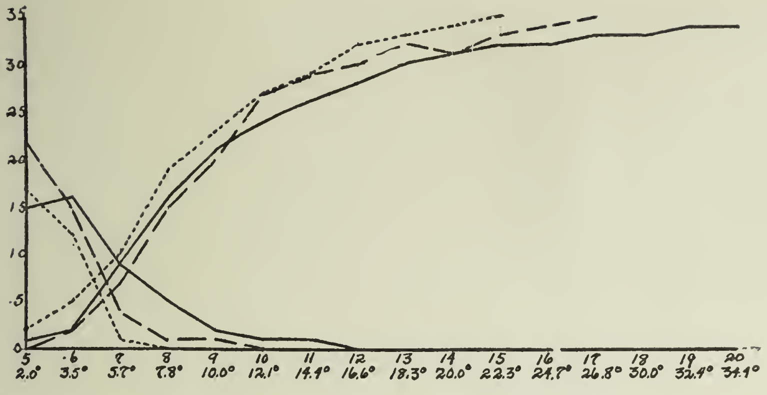

Fig. 3. Recognitive Limens for the Yellow Disk.

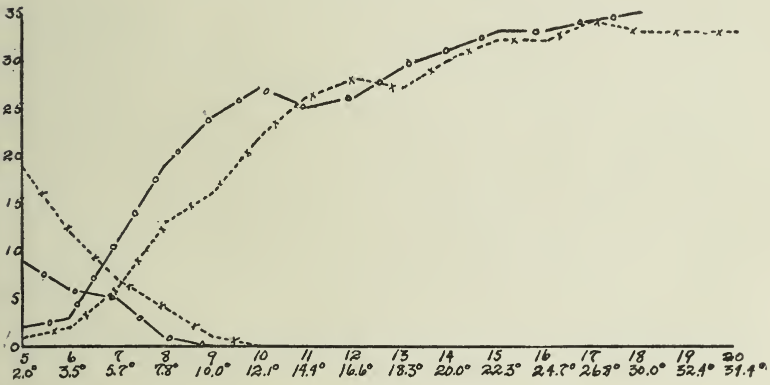

Fig. 4. Recognitive Limens for the Yellow Disk.

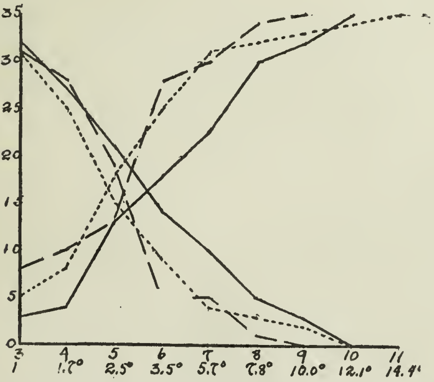

Fig. 5. Recognitive Limens for the Green Disk.

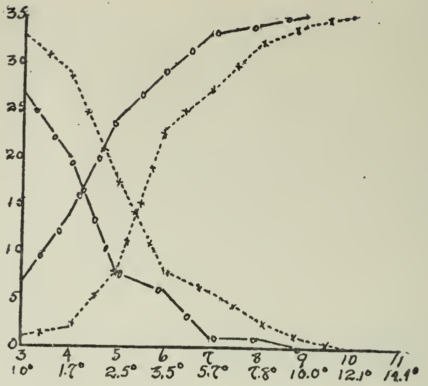

FIG. 6. Recognitive Limens for the Green Disk.

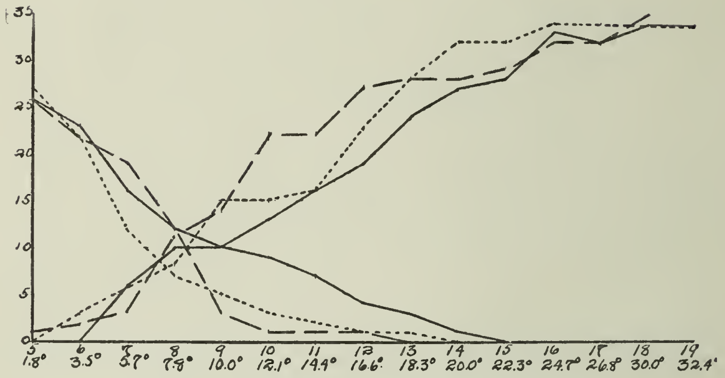

FIG. 7. Recognitive Limens for the Red Disk.

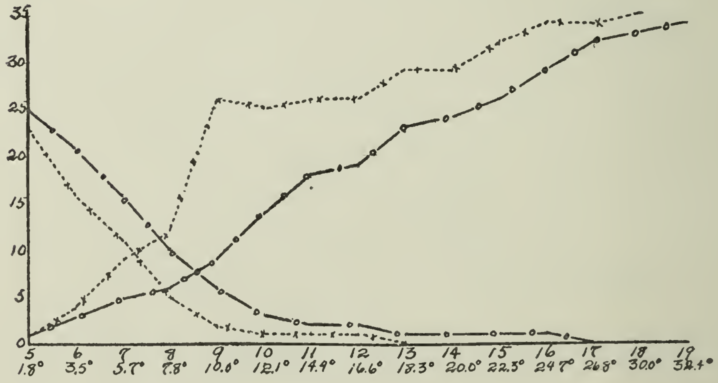

FIG. 8. Recognitive Limens for the Red Disk.

curves (Figs. 1 to 8), mark the recognitive limens for the various colors with and without the effects of primary stimulation. Since at the point of intersection the number of color judgments and black judgments is equal, this was termed the recognitive limen. The limens for the four colors of the color discs as influenced by the four inducing colors are arranged in an ascending series in Fig. 9. This sets forth in a diagrammatic way not only the amounts of color necessary for the recognition of a given color with different influences but also the relation of all the limens of one color with the limens of the remaining three colors.

TABLE III

COMBINED RESULTS OF ALL OBSERVERS FOR BLUE WITH NO INFLUENCE

Judgments	Micrometer Readings in Eighths											
	5	6	7	8	9	10	11	12	13	14	15	16
Bk	27	23	19	10	5	2	1	1	1	1	1	
DkBl		1	1	3	1	3	2					
BlBk	2	4	4	7	5	2						
Bl			4	8	17	26	31	34	34	34	34	35
P	1		1	3								
DkP	1	1										
GrBk	1	1	1	1								
DkGr	1	1	1	1	3							
Br	1	2										
BlP		1	1	2	3	2	1					
R	1	1	1									
PBr			1									
PBk			1									
Gr					1							

AGGREGATION OF RE-CLASSIFIED JUDGMENTS

Bk	27	23	19	10	5	2	1	1	1	1	1	
Bl	2	6	10	20	26	33	34	34	34	34	34	35
P	2	1	3	3								
G	2	2	2	2	4							
R	1	1	1									
Br	1	2										

Numerals under the micrometer readings signify the number of observers making a given judgment. 'With No Influence' means the absence of primary stimulation. The term 'Blue,' preceded by 'with No Influence,' refers to the color of the disk (secondary stimulus), on which judgments are made. Similar explanations apply to Tables IV. to XXII. inclusive. All judgments other than Bk and Bl, except as indicated above, are random judgments; they represent hazards and are not incorporated in the curves. Similar judgments are found in Tables IV. to XXII. inclusive.

TABLE IV

RESULTS OF ALL OBSERVERS FOR BLUE WITH BLUE INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths								
	5	6	7	8	9	10	11	12	13
Bk.	20	15	8	7	3	1			
Bl.	10	17	22	24	31	32	34	35	

TABLE V

RESULTS OF ALL OBSERVERS FOR BLUE WITH YELLOW INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths											
	5	6	7	8	9	10	11	12	13	14	15	16
Bk.	22	14	10	3	2	1	1	1	1	1	1	
Bl.	6	14	22	27	30	34	34	33	34	34	34	35

TABLE VI

RESULTS OF ALL OBSERVERS FOR BLUE WITH GREEN INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths									
	5	6	7	8	9	10	11	12	13	14
Bk.	19	11	6	3	2	1				
Bl.	9	15	23	27	31	34	33	35	35	35

TABLE VII

RESULTS OF ALL OBSERVERS FOR BLUE WITH RED INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths									
	5	6	7	8	9	10	11	12	13	14
Bk.	27	14	4	4	2					
Bl.	6	15	23	26	32	35	35	35	35	35

TABLE VIII

RESULTS OF ALL OBSERVERS FOR YELLOW WITH NO INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths															
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Bk.	15	16	9	5	2	1	1									
Y.	1	2	9	16	21	24	26	28	30	31	32	32	33	33	34	34

TABLE IX

RESULTS OF ALL OBSERVERS FOR YELLOW WITH BLUE INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths															
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Bk.	17	12	1													
Y.	2	5	10	19	23	27	29	32	33	34	35					

TABLE X

RESULTS OF ALL OBSERVERS FOR YELLOW WITH YELLOW INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths															
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Bk.	22	15	4	1	1											
Y.	0	2	7	15	20	27	28	30	32	31	33	34	35			

TABLE XI

RESULTS OF ALL OBSERVERS FOR YELLOW WITH GREEN INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths															
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Bk.	19	12	7	4	1											
Y.	1	2	6	13	16	22	26	28	27	30	32	32	34	33	33	33

TABLE XII

RESULTS OF ALL OBSERVERS FOR YELLOW WITH RED INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths															
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Bk.	9	6	5	1												
Y.	2	3	11	19	24	27	25	26	29	31	33	33	34	35		

TABLE XIII

RESULTS OF ALL OBSERVERS FOR GREEN WITH NO INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths							
	3	4	5	6	7	8	9	10
Bk.	32	27	21	14	10	5	3	
Gr.	3	4	13	18	23	30	32	35

TABLE XIV

RESULTS OF ALL OBSERVERS FOR GREEN WITH BLUE INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths								
	3	4	5	6	7	8	9	10	11
Bk	29	25	15	9	4	3	2	1	
Gr	5	8	18	25	31	32	33	34	35

TABLE XV

RESULTS OF ALL OBSERVERS FOR GREEN WITH YELLOW INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths							
	3	4	5	6	7	8	9	10
Bk	31	28	19	5	5	1		
Gr	3	5	13	28	30	34	35	

TABLE XVI

RESULTS OF ALL OBSERVERS FOR GREEN WITH GREEN INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths								
	3	4	5	6	7	8	9	10	11
Bk	33	29	18	8	6	3	1		
Gr	1	1	8	23	27	32	34	35	

TABLE XVII

RESULTS OF ALL OBSERVERS FOR GREEN WITH RED INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths							
	3	4	5	6	7	8	9	10
Bk	27	20	8	6	1	1		
Gr	7	14	24	29	33	34	35	

TABLE XVIII

RESULTS OF ALL OBSERVERS FOR RED WITH NO INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths														
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Bk	26	23	16	12	10	9	7	4	3	1					
R	0	0	6	10	10	13	16	19	24	27	28	33	32	34	34

Table XIX

Results of All Observers for Red with Blue Influence

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths														
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Bk.....	27	22	12	7	5	3	2	1	1						
R......	0	3	6	8	15	15	16	23	28	32	32	34	34	34	34

Table XX

Results of All Observers for Red with Yellow Influence

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths														
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Bk.....	26	22	19	12	3	1	1	1							
R......	1	2	3	11	14	22	22	27	28	28	29	32	32	35	

Table XXI

Results of All Observers for Red with Green Influence

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths														
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Bk.....	23	16	11	5	2	1	1	1							
R......	1	4	9	12	26	25	26	26	29	29	32	34	34	35	

Table XXII

Results of All Observers for Red with Red Influence

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths														
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Bk.....	25	21	16	10	6	3	2	2	1	1	1	1			
R......	1	3	5	6	9	14	18	19	23	24	26	29	32	33	34

VI

Results.—Figs. 10 and 11 show the recognitive limens in condensed form for the four primary colors with and without the influence of primary stimulation; they also throw into clear relief the quantitative relations of the various limens. As already indicated these limens are the intersecting points of the curves grouped in Figs. 1 to 8 inclusive.

TABLE XXIII

DEGREES OF COLOR COMMENSURATE WITH MICROMETER READINGS

Eighths	Blue	Color Disks Yellow	Green	Red
4	1.2	1.2	1.7	0.7
5	2.0	2.0	2.5	1.8
6	3.5	3.5	3.5	3.5
7	5.7	5.7	5.7	5.7
8	7.8	7.8	7.8	7.8
9	10.0	10.0	10.0	10.0
10	12.1	12.1	12.1	12.1
11	14.4	14.4	14.4	14.4
12	16.6	16.6	16.6	16.6
13	18.3	18.3	18.3	18.3
14	20.0	20.0	20.0	20.0
15	22.3	22.3	22.3	22.3
16	24.7	24.7	24.7	24.7
17	26.8	26.8	26.8	26.8
18	30.0	30.0	30.0	30.0
19	32.4	32.4	32.4	32.4
20	34.4	34.4	34.4	34.4

Reference to Figs. 10 and 11 indicates the following results:

1. The recognitive limens for blue (7.5–6.7°),[1] red (9–10°) and green (5.4–2.9°) 'without influence' are higher than any other limens for these colors when 'influenced by the after-effects of primary stimuli.'

2. The five limens for blue, red and green form identical series, as to sequence, of decreasing magnitudes. These series conform to the following order of primary stimulations: red, yellow, blue and green. While the relative values of the limens in these three series remain the same, their absolute values vary. For example, the limen for blue, determined after stimulation for red, is 6.1–3.7° while for red under the same conditions the limen is 8.6–9.10° and for green 4.3–1.9°. The maximum and minimum limens for green, blue and red under identical conditions with respect to previous stimulation are 5.7–3.3°; 4.3–1.9° (green), 7.5–6.7°; 5.7–3° (blue) and 9–10°; 7.2–6.1° (red). The differences of these maxima and minima in the direction of red are 3.3–6.7°; 2.9–4.1° and 1.5–3.3°; 1.5–3.1°.

3. The sequence of limens for yellow varies somewhat from those for blue, green and red. In the case of yellow two of

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[1] 7.5–6.7° = micrometer readings (7.5 eighths) and degrees of color (6.7°).

the limens fall together, *i. e.*, the limen for yellow without the after-effects of primary stimulation and the limen with the after-effects of previous stimulation with green is 7.1–5.9°. The sequence of limens for yellow following the order of primary stimulations as shown in the graph (Fig. 11) is: Green (none), yellow, blue and red.

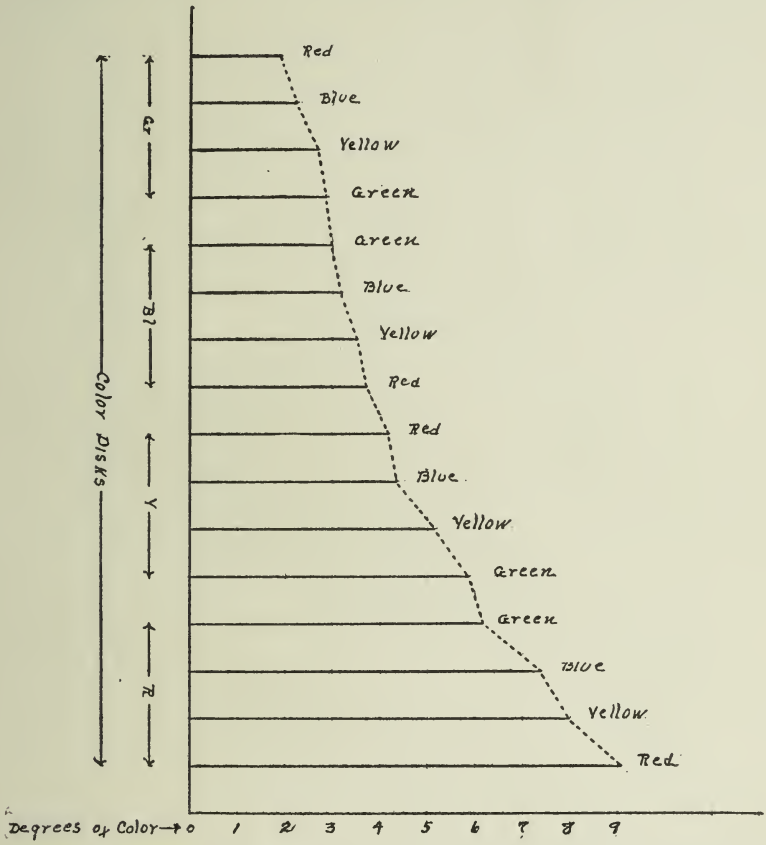

FIG. 9. Quantitative relationship of the various limens for the secondary stimuli (color disks). The terminal readings of the various abscissæ indicate the limens of color sensitivity for the four secondary stimuli as influenced by the different inducing colors. The names of the colors at the ends of the lines indicate primary stimuli (inducing colors).

4. The limens for red corresponding to the limens for the three other primary colors are throughout the highest; those

for green are throughout the lowest; while the corresponding limens for blue and yellow fall between the two extremes of the limens for red and green. Fig. 9 represents the relative positions graphically. It will be noted, and this is interesting, that the antagonistic colors red and green have throughout

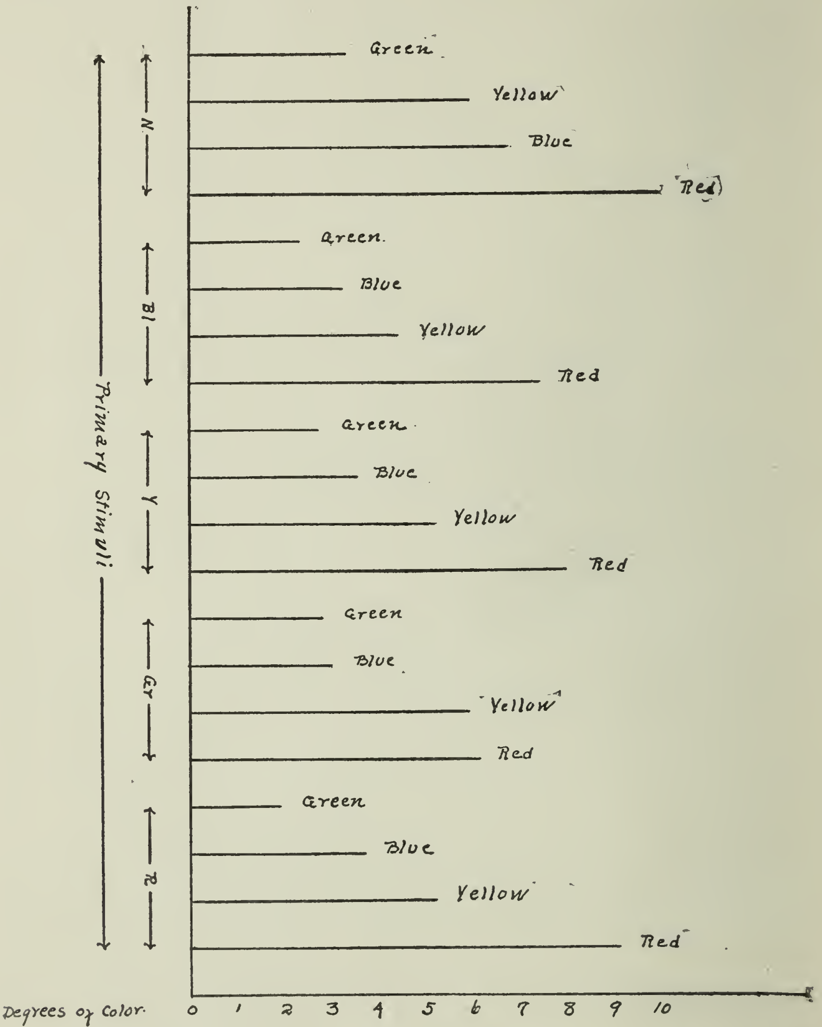

FIG. 10. Limens of sensitivity with and without induction. Color names at the ends of lines indicate the secondary stimuli (color disks). The terminal readings of the various abscissæ indicate the limens of color sensitivity for the four primary colors as influenced by the different primary stimuli.

the highest and the lowest limens respectively while the limens for the complementary colors blue and yellow fall between these two extremes.

Conclusions.—The duration and character of the after-effects of stimulation are so varied and elusive, the exact composition of color papers so difficult of precise determination, the condition of the retina and the composition of incandescent lights so variable and the influence of eye-movements, practice and fatigue so important that deductions from the data should be made with the greatest care.

1. When the after-effects of a primary stimulus is similar to the color of the disc the limen is the lowest of the five limens for this color. This is true for the green, yellow and red color discs employed in this experiment. In these cases the limens are 4.3–1.9°; 6.4–4.4° and 7.2–6.1° respectively. An exception to this conclusion is found in the case of the blue disc in which case the lowest limen is connected with

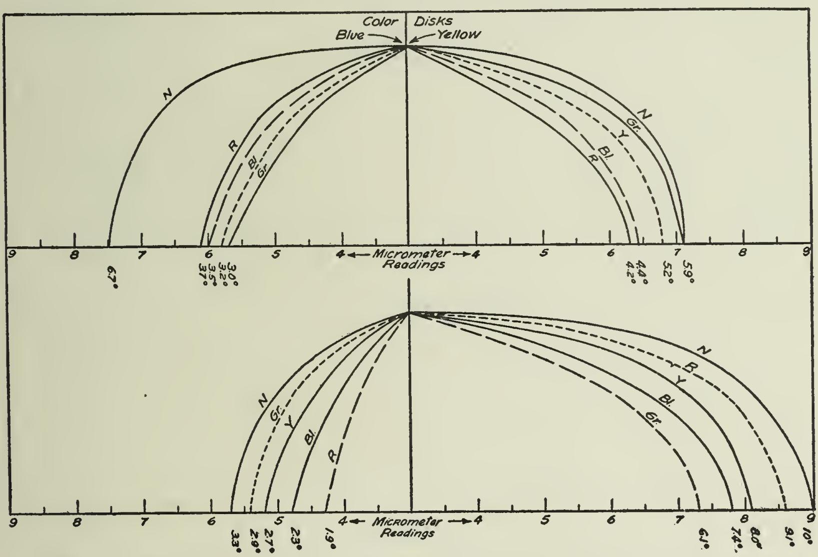

FIG. 11. Recognitive limens as given in micrometer readings and degrees of color. Color abbreviations on curved lines indicate the colors of the primary stimuli. *N* = primary stimulus lacking. ...., indicate primary stimuli followed by after-images complementary to colors on vertical line. —— ——, ——, indicate primary stimuli complementary to colors on vertical line. The points on the vertical line were arbitrarily chosen.

green rather than a primary stimulation of yellow as we might expect. The explanation is probably found in the difference of brightness values of the after-effects of blue and green stimulations, the effects of the latter in this respect being greater. The difference between these two limens is, however, very slight, being .3/8 micrometer reading or .2° of color. In this connection it is interesting to note that Parsons[1] observed: "If the secondary stimulation is the complementary color of the primary, the resulting sensation is that of an extremely saturated complementary color." The lowest limens for the green, yellow and red colors are cases in which the primary stimuli are complementary colors, *i. e.*, red for the bluish green, blue for the yellow and bluish green for the red. The after-images for these primary stimuli would, therefore, be same-colored as the colors on the discs, and tend to raise the saturation of these colors. It is altogether likely that the saturation of the after-image exceeds that of the color on the discs so that the total effect is a compromise between the degree of color with reference to its saturation and the after-image.

With reference to the saturation of a spectral color Parsons[1] observes: "It may be far more saturated than any spectral color so that it is impossible to obtain a comparison light which will match it." The investigations of v. Kries[2] and his students on the effect of the after-images on color matches are instructive in this connection. He found that a yellow paled or became more saturated according to whether the after-image was blue or yellow. It appears that we may probably conclude that the lowest limens for green, yellow and red are traceable to an increase in saturation due to the after-effects of the primary stimuli complementary to these colors.

2. When the primary stimulations are not complementary to the secondary stimulations the influence of the effects of primary stimuli upon the recognitive limens of the secondary stimuli is more difficult to trace. From Fig. 10 it is seen that

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[1] Parsons, *op. cit.*, p. 109.

[2] Citation from Parsons' 'Introduction to Color Vision,' p. 105.

the limens for the colors here investigated are, in eleven cases out of twelve, lower when the primary stimuli are not the complementary of the secondary stimuli. The exception is the limen for yellow when the primary stimulus is green. This limen falls together with the limen of yellow when uninfluenced by primary stimulation.

Theoretically, and perhaps upon the basis of the work of v. Kries (quoted above), we might expect a higher limen for a given color when the after-image of a primary stimulus is complementary to this color. For example, a blue after-image pales a yellow color. If the degree of saturation is a determinant of color recognition then we should expect higher limens for colors when influenced by after-images which are complementary (antagonistic) than when primary stimulations are lacking. Our results are not, in the main, in accord with this expectation. Moreover, our color limens are (except for yellow, in which case the limen is equal) lower when influenced by after-images which are neither complementary to nor same-colored as the color discs than when primary stimulations are entirely lacking.

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